Gravity/Topography Admittances for Corona-Dominated Rises on Venus: Evidence for Delamination.

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Coronae are approximately circular features unique to Venus. They are interpreted as small scale mantle upwellings and range in size from approximately 100 to 1000 km in diameter. An important question is the relationship between coronae and large volcanic rises, or hotspots, the surface manifestation of larger-scale mantle upwellings. Hotspots on Venus have been classified into three groups: riftdominated rises, corona-dominated rises, and volcano-dominated rises [1]. The three corona-dominated rises (CDRs), Themis, Eastern Eistla and Central Eistla Regiones, are clusters of coronae that lie on broad topographic rises greater than 1000 km in diameter and have large gravity anomalies characteristic of hotspots. Each of the three CDRs exhibit a strikingly similar gravity/topography admittance signature that differs from the signature found at other hotspot rises [2-4]. Admittances at CDRs can be interpreted as indicating a relatively thin elastic lithosphere and a thin crust, or as a dynamic signature due to delamination. Below we argue in favor of the interpretation that the signature is best interpreted as evidence for delamination of the lower lithosphere beneath coronae.

A large gravity high is associated with the broad topographic highs at each of the CDRs. In addition many of the coronae with significant topography correspond to smaller gravity highs. The gravity highs corresponding to the broad topographic swells suggest the presence of a plume at depth. The gravity/topography admittance spectra for the three regions are shown in Figure 1. At short wavelengths the admittance signature has a steep positive slope that is characteristic of an elastic lithosphere being loaded from above [2], such as by a volcano. This type of signature is observed at Bell, Atla, and Beta Regiones [2-4]. Fitting the short wavelength portion of the spectra with a top loading model results in values of elastic thickness (Te) of 12, 22, and 12, km and crustal thicknesses (D) of 5, 10, and 20 km for E. Eistla, Themis, and C. Eistla, respectively. These values have an uncertainty of approximately ±5 km as elastic thickness and crustal thickness can be traded off, with smaller values of elastic thickness giving larger crustal thicknesses (see Figure 1). Fitting the long wavelength portion of the data with a bottom loading model, as is expected for a plume loading the base of the lithosphere, gives somewhat thicker values of Te of 25±5 km in at E. and C. Eistla and 35±5 km at Themis. The long wavelength values of apparent depths of compensation (ADCs) are 80-90 km for the three regions. The ADC gives an approximate estimate of the depth to the plume and the base of the thermal lithosphere.

The estimates of crustal, elastic, and thermal lithospheric thicknesses are distinctly different from values found at other hotspot rises. Elastic thickness estimates are available for 2 of the 4 volcano-dominated rises: Bell and W. Eistla Regiones. At Bell Regio, a volcano-dominated rise, the elastic thickness estimate from the short wavelength portion of the spectrum is in the range of 20-30 km [2, 4] and 40 km at long wavelength [2]. At W. Eistla Te is estimated to be 25 km assuming a D=30 km, although it is a bottom loading signature only. Te estimates have been made for both of the rift-dominated rises, Beta and Atla Regiones. For Atla Regio Te is estimated to be 30 km with D=30-40 km [2-4]. Estimates for Beta Regio are D=20-40 km, Te = 10-20 km. ADCs for Bell, Atla, W. Eistla, and Beta Regiones are approximately 125, 175, 200, and 225 km. As a group, CDRs have generally smaller Te values than at other large rises. The small estimates of D derived from fitting the slope of the short-wavelength portion of the admittance spectrum for CDRs is not observed at other rises. As result of using a small value of D, the ADCs of 80-90 km are also much smaller than the values of 125-225 km found at other rises. Relative to other coronae, Te values are at the lower end of the typical 10-35 km range [5].

We propose two interpretations for the distinctive gravity signatures found at CDRs. The first is a straightforward interpretation that various volcanic features found at these coronae are responsible for the top-loading signature while a plume causes bottom-loading at depth. The small estimates of elastic and thermal lithospheric thickness may indicate thermal thinning and a general increase in the thermal gradient due to the presence of a plume. Within the context of this interpretation there is no ready explanation of the small values of crustal thickness. Crustal thicknesses estimates for both other large volcanic rises and all other regions on Venus are approximately 30 km [4, 6], a factor of two greater than the average at CDRs. Further, one would expect regions of substantially thinner lithosphere underlain by plumes to exhibit extremely large volumes of volcanism, comparable or greater than that observed at volcano-dominated rises.

Corona morphology, models of corona formation, and geologic history of the three regions suggest an alternative explanation. Smrekar and Stofan [7] proposed a model of coronae formation that includes delamination of the lower lithosphere as a result of mantle upwelling and that can produce the full range of observed corona topographic groups. Examining the morphology of coronae in E. Eistla in the context of this model indicates that they are in a late stage of formation and require both prior delamination of the lower lithosphere and the presence of a depleted mantle layer at depth [8]. At C. Eistla and Themis the coronae are in varying stages of evolution. The morphologies are consistent with both delamination and a depleted mantle layer, but do not require them.

The gravitational signature of a delaminating lower lithosphere mimics that of a top loading model. Delamination pulls down on the lithosphere in much the same manner as top load depresses the surface from above, resulting in a similar signature. Within this interpretation, elastic thicknesses are probably comparable to those obtained using the top-loading model but are not estimated explicitly. Similarly, the apparently small values of crustal thickness cannot be interpreted as real but rather reflect differences in the signature of being pulled down relative to being pushed down. The shallow ADCs are a result of imposing an artificial small crustal thickness.

We advocate the a combined top-loading and dynamic topography for two reasons. First, the coronae morphology in these regions either requires or is consistent with delamination. Further at Eastern Eistla Regio, there are no constructional volcanic features and thus no obvious source of top-loading. Second, the inferred crustal thicknesses for at least E. Eistla and Themis Regio are well below values of ~30 km found elsewhere on Venus [6] and are thus unlikely to be real. We interpret the fact that the smallest crustal thickness (5 km) is found at E. Eistla as being a 'pure' delamination signature, since all of the corona forms at E. Eistla require delamination and there are no obvious surface loads. At C. Eistla and Themis, there are volcanos present and the corona are in a range of evolutionary stages. Thus the somewhat larger values of crustal thickness (10, 20 km) and elastic thickness (22, 12 km) for Themis and C. Eistla may indicate a combined delamination and top-loading signature.

The evidence for multiple stages of evolution of the various coronae at Themis and C. Eistla argues against the idea that corona clusters are a result of instabilities formed simultaneously due to break-up of a plume head as it impinges on the lithosphere [1, 8]. Rather small-scale plumes with durations sufficient to allow the production of complex coronae morphologies and delamination and which are not spawned simultaneously appear to be required. Individual rising blobs with out tails do not produce the full range of corona topography [7]. Such short lived upwelling may form the large volcanos observed on Venus.

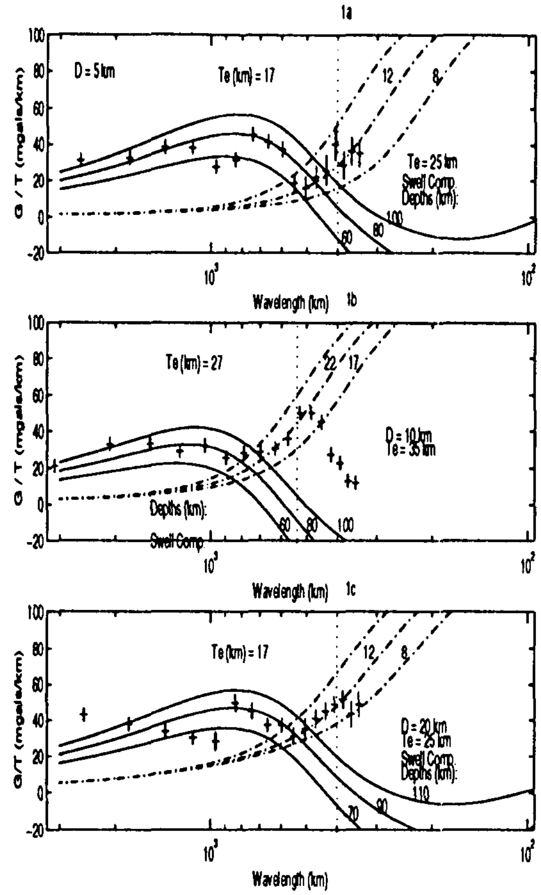

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Figure 1. Gravity/Topography admittances for E. Eistla (a) Themis (b) and C. Eistla (c). nSolid lines are bottom loamodels. Dash-dot lines are top g models. The vertical dotted line is the approximate cut-off of the resolution in gravity data. All admittances are calculated using MGNP180U.